Piper PA-34-200-2 Seneca, G-BARB, 20 January 1994

Bulletin Addendum

Ref: EW/C94/1/4 Category: 1.3

Aircraft Type and Registration:	Piper PA-34-200-2 Seneca, G-BARB
No & Type of Engines:	2 Lycoming IO-360-C1E6 piston engines
Year of Manufacture:	1973
Date & Time (UTC):	20 January 1994 at 1722 hrs
Location:	Near Bloxwich, West Midlands
Type of Flight:	Private
Persons on Board:	Crew - 1
	Passengers - 3
Injuries:	Crew - Fatal
	Passengers - Fatal
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Private Pilot's Licence with Instrument Rating
Commander's Age:	29 years
Commander's Flying Experience:	1,108 hours (of which 722 were on type)
	Last 90 days - 28 hours
	Last 28 days - 8 hours
Information Source:	AAIB Field Investigation

Previous AAIB Bulletin report

The report on this accident was included in AAIB Bulletin 8/94. Despite a very detailed investigation, no cause for the accidentwas satisfactorily identified. The report made at that time issummarised below:

The pilot and his 3 passengers were returning to Ronaldswayafter a business meeting; the same personnel had flown to Birminghamin the same aircraft early that morning. Subsequent calculationsshowed that G-BARB was below maximum weight for take off and waswithin cg *limits.*

At the time of departure, the visibility was 15 km and themean sea level pressure was 1025 mb. There was scattered cloudfrom 2,000 to 3,000 feet, scattered to broken cloud at 6,000feet with tops around 9,000 feet and thin layers above. The surfacewind was 260°/10 kt with a temperature of plus 9°Cand the wind at 6,500 feet was 310°/35 kt ,with a temperatureof plus 3°C. There was also the possibility of mountainwave activity in the area, but subsequent enquiries revealed noreports of turbulence.

Reconstruction of the accident flight was achieved usingRT recordings and secondary radar recordings. G-BARB took offfrom Birmingham at 1711 hrs and once airborne, the aircraft wastransferred to Birmingham Approach and then to Manchester ATC. G-BARB was then cleared to FL80, but the pilot requested andwas given clearance to maintain FL60; his acknowledgement of thiswas the last recorded message from the aircraft. At 1722 hrs,the Manchester controller noticed that he had lost the radar returnand, after unsuccessful radio calls, initiated crash action.

The radar recordings initiated with the aircraft leaving Birminghamand climbing through 100 feet. Subsequent radar returns wereobtained at 8 second intervals and showed the aircraft climbingto FL60. Based on the aircraft weight, the rate of climb andspeed were normal and the aircraft maintained a constant track. The aircraft climbed to FL60, but started a descent almost immediately. The radar showed the rate of descent increasing rapidly to amaximum of approximately 11,000 ft/min. During this time theaircraft track changed from north westerly to southerly. Basedon the radar information, G-BARB could have rolled left with anincreasingly low nose attitude or could have rolled right throughthe inverted position onto the southerly heading.

Various witnesses reported seeing and hearing the aircraftduring the later part of the flight. There were reports of unusualengine noises and certain eyewitnesses saw the aircraft levelat approximately 800 feet agl heading in a north westerly direction. A few witnesses saw some flames from the aircraft and there werereports of something falling off. All those who saw the lastmoments of flight described the aircraft rolling and apparentlyout of control. It was dark at the time of the crash.

Post-mortem examination of the occupants revealed no medicalcondition which could have contributed to the accident.

G-BARB had come to rest on common land about 100 yards eastof the M6 motorway. The aircraft was inverted and the completeempennage and both wings outboard of the flaps were missing. It had struck the ground with high vertical velocity and withsome motion towards the left (port) engine, but with little orno forward speed. Neither propeller showed evidence of powerat impact. The missing portions of the wings, rear fuselage andtail were found at various locations over the adjacent built-uparea of Bloxwich at distances of up to half a mile from the mainwreckage. From the track of the aircraft and the winds obtainedfrom a Meteorological Office aftercast , a wind-drift plot wascompiled. This indicated that the detachment of the outboardwings and tail section had occurred over a period of not morethan a few seconds at a height of approximately 1,500 to 2,000feet agl.

The wreckage break-up pattern indicated that the right andleft wingtips, each complete with an outboard fuel tank, had separatedfrom the aircraft in a similar manner. The right wingtip hadthen *struck the right stabilator, causing it to break away inan upwards direction, and causing the rest of the empennage toseparate at about the same time. There was no evidence of fatigueor other pre-existing structural defects. There was evidencethat the wingtips had separated in a downwards bending mode associated,in the case of the right tip, with a nose-down pitching momentand there was also evidence on both wings of load reversal. Thissuggested a short period during the return to level flight whenthe aircraft had been overstressed to the point of structuralfailure. This was considered consistent with the high verticalspeed shown by the radar data, which implied a high airspeed witha probability of high structural loads during the recovery. Noevidence of flutter as an initial event was found.*

The flying controls were examined in detail and although itwas not possible to discount a possible temporary control jam,it was established that the controls had been connected and appearedto have been serviceable. The components of the pitch trim systemfunctioned acceptably after the accident and bore no indicationsof pitch trim 'runaway'. The autopilot console, servos and amplifierall functioned normally when tested.

Detailed examination of the engines and propellers establishedthat they were capable of operation and were in fact running atlow power at impact. Both propellers had stopped in about onerevolution, or less, while at pitch angles indicating transitionto the feathered position. This was considered the result ofloss of oil pressure to the propeller governors which would haveoccurred almost immediately upon inversion of the aircraft. Noevidence of any fuel related problem was found. There was someevidence of an oil leak from the right engine, however examinationof the oil uplifts record suggested that the leak was of a minornature. The positions of the controls and indications on theinstruments also indicated that neither engine had been shut downand that the aircraft systems were in a normal configuration. Filament analysis of several instrument lighting bulbs indicatedthat electrical power had been available to the system buss, andtherefore to all the subsystem circuit breakers, at impact. Theinvestigation of the vacuum instruments, system and de-icing systemshowed that the attitude gyro had been running normally at impact.

The AAIB Bulletin concluded that *"It was apparent thatthe aircraft had been recovered from this descent at some stagebut that during this recovery it had been subjected to excessiveforces which caused structural failure. Something happened whileG-BARB was levelling at FL60 to cause the loss of control. Anextensive engineering investigation was able to discount all likelyengineering or technical causes which may have contributed tothe accident. However, it remains possible that some technicalor other problem occurred which may have been resolved in theair but which nevertheless initiated the loss of control."*

Reopened Investigation

On 1 December 1994 a Dutch registered Piper Seneca III crashedat Radscheid in Germany. The aircraft was on an IFR trainingflight in day VMC from Stuttgart to Maastricht with an instructoron board, one student handling the controls and one student inthe rear of the aircraft. The handling pilot was a commercialstudent near the end of his training. The accident occurred asthe aircraft was approaching the border with Belgium, trackingthe NTM (Nattenheim) VOR at FL100 with the KING KFC 200 autopilotin ALT HOLD mode. The aircraft was given a descent clearanceto FL60 but although this was acknowledged the radar recordingshowed that the aircraft did not begin to descend until almosta minute later when it entered a rapidly and increasingly erraticdescent during which the track reversed. The aircraft sufferedstructural failure loosing the outer wings and the empennage;the wing also failed at the centre joint. The German AccidentInvestigation Bureau (LBA) found that the autopilot disconnectmicroswitch was defective and on the basis of that, and othersupporting evidence, concluded that the accident had been causedby failure of the autopilot to disengage when required by pilotoperation of the trim switch. Such a condition would cause theautopliot to trim 'nose up' as the control wheel was pushed forward. There are specific warnings about this situation in the KingKFC 200 autopilot manual and in the Seneca III Flight Manual. The radar data showed that the aircraft had lost energy initiallyand in this regard Piper suggested that the aircraft had probablyspun following the pitch up, concluding that it had then enteredan accelerating descent and had broken up in the subsequent recovery.

On 7 May 1995 an incident occurred involving a Beech 95A Travelairregistration G-ATRC. This was reported in AAIB Bulletin 9/95. The Beech Travelair is a light twin, generally similar to theSeneca. In particular it has a large trim tab on the rudder. Approximately 10 minutes after taking off the pilot felt slightvibration through the rudder pedals. After applying right rudderthe rudder jammed, causing the aircraft to sideslip. The vibrationthen became so severe that the pilot had difficulty in keepinghis feet on the rudder pedals, and could not read the instruments. The sideslip continued, with the pilot unable to maintain heightand experiencing pitch control difficulties. He also reporteda stall warning at 120 kt IAS as power was reduced. The pilotdeclared an emergency and with assistance from ATC landed safelyat a nearby airfield some 10 minutes later. He had eventuallybeen able to level the aircraft using differential power at about700 ft. The pilot stated that he had been fortunate to regaina measure of control. Subsequent examination of the aircraftshowed that the rudder trim tab actuating rod had fractured atits attachment to the rudder trim jack, which is mounted in therear of the fin. This had left the major portion of the rod stillattached to the tab. Once the failure had occurred, the tab hadbeen free to 'flutter' and to act as an uncontrolled 'servo-tab'giving rise to the violent pedal movement. On examination itwas found that the failed end could be made to foul on the rudderin such a way that the tab was unable to return to centre, possiblyaccounting for the reported rudder jam. The failure was attributedto fatigue caused by incorrect assembly of the actuating rod. In discussion with the AAIB engineering inspector involved itwas apparent how much difficulty this pilot had encountered andhow little evidence on the structure there was of flutter-likedamage.

As a result of these events, a re-examination of the wreckageof G-BARB was conducted and this included a search for more subtleevidence of flutter damage and for any mechanism by which therudder tab might jam. The earlier investigation had found notrim switch defect associated with G-BARB and the autopilot wasa Piper Altimatic III rather than the King type fitted to theDutch aircraft. There was also no indication of pitch controlproblems either from radar and energy plots, or from the examinationof the pitch trim mechanism. Some points of similarity were noted,however, in particular the rudder tab linkage attachments on thetab were both broken and in both cases a similar fragment wasmissing from one bracket (Figure 1shows general arrangement ofSeneca fin, rudder and trim tab; Figure 2 shows damaged brackets). The Dutch aircraft's fin and rudder had not been damaged severelyin the ground impact and so it was possible to see that some minordamage had occurred due to some type of flutter-related phenomenon. In particular, the rudder top hinge had compression damage onboth sides, suggesting cyclic motion against mechanical limitswith large deflections of the structure. The rudder of G-BARBexhibited similar damage to the top hinge, as shown in Figure3, but this had not been identified earlier because it had beenmasked by ground impact damage. There was no other evidence,such as elongated 'cutouts' or overtravel damage at the hingepoints, but significant free play was found in the top and bottomrudder hinges, and significant cracking of the paintwork was foundon the rudder, but not on the fin or tab. This cracking ran alonglines of rivets at the leading and trailing edges and in diagonalpatterns across the rudder skins in a manner suggestive of torsionaldeflections. Lines of corrosion had formed within the cracks,but not where the paint had completely flaked off, indicatingthat the cracking had existed for some time before the crash occurred(Figure 4).

Severe scoring of the paint was found inside the trailing edgeof the rudder. This had been caused by forcible contact withthe tab leading edge shroud and showed that the tab had been deflected42° to the right (left rudder) at some time (Figure 5). It was possible that this could have occurred during maintenancewith the tab disconnected. Normal tab travel is 22° right,17° left, with the rudder moving 35° each way. It wasnot possible initially to displace the tab as far as 42°due to the rivets on the right hand leading edge of the tab foulingthe rudder trailing edge skin. Many of these rivet heads hadtheir paint removed due to contact with the rudder skin, and therewere corresponding marks in the skin. The tab could be movedwith some effort to align with the paint marks made by the shroud,whereupon the tab became jammed in the rudder. By comparisonwith the Dutch Seneca, the geometry of the tab and rudder representedan unusual combination of manufacturing limits as the rivets onthe tab of the Dutch aircraft had remained clear of the rudderskin. That aircraft also had a bonding lead and bolt on the ruddercentreline which had damaged the shroud of the tab, while at thesame time restricting its free deflection, preventing it fromreaching an angle at which a jam might occur. Figure 6 showsthe area of the trim tab and rudder on G-ATRC, which exhibitedno evidence of flutter or tab/rudder jamming.

Because of the possible significance of the tab having becomedisconnected, a metallurgical report was commissioned to examinethe fracture faces of G-BARB's rudder tab brackets. The reportdrew a number of conclusions, the most important of which were:

A small piece of the lower bracket retained by the pivot bolthad rotated relative to the upper bracket, even though both facesof both brackets had been crushed during tightening of the pivotbolt (this tightening is normal as it ensures that all rotationrelative to the operating rod takes place within the bearing).

Part of the fracture face had been damaged by 'chafing' whichhad destroyed the major part of any fractographic evidence.

The paint on the lower bracket contained a series of parallelcracks; these cracks contained accumulated debris suggestingthat plastic deformation of the bracket had occurred some timebefore the accident. The report suggested that the bracket couldhave been bent and straightened-out at some time.

The rivets attaching the tab brackets were tubular. Drilled offrivet tails were found inside the tab. The report suggested thatthe rivets were part of a repair scheme.

The bearing showed no evidence of lubricant, but considerablequantities of compacted debris were found within it.

The report noted that at sub zero temperatures accumulated moisturewould make the bearing stiff and that a similar mechanism waswell known to apply to strip hinges such as that used to attachthe tab to the rudder. As the tab was an anti-servo tab, normalmovement of the rudder would result in abnormal loading of themechanism at sub-zero temperatures, even though clear of icingconditions. Many light aircraft are fitted with similar striphinges.

The metallurgist's report was sent to the German investigatingauthority who reported that no evidence of fatigue or chafingcould be identified in their case. It was concluded that theDutch aircraft had experienced flutter-like behaviour of the finand rudder either during the attempted recovery or during thebreakup, and this had caused the tab brackets to break up. G-BARBhad experienced a similar motion late in the flight but, unlikethe Dutch Seneca, damage due to low amplitude flutter-like vibrationhad been progressively building in the rudder and tab linkagebefore the accident flight.

Nine other Piper Seneca aircraft were examined. On one of theseit was evident from damage to paint on the rivet heads that therudder trim tab, if over-rotated, would jam as the rivets passedunder the rudder skin. In this case it was likely that the paintdamage had occurred during maintenance. The eight other aircrafthad greater clearance between the tab and rudder. In spite ofcomments from several engineering organisations that there wereno particular maintenance problems with the tab brackets, themajority of the aircraft examined either had loose rivets in thearea or had been repaired, in one case by substituting steel brackets,as shown in Figure 7. It was felt that these repairs, which involvedmostly the replacement of loose rivets, were considered minorand sometimes were not documented.

Piper Service Bulletin 390A, dated May 30 1973, addressed theproblem of excessive free play in the rudder trim tab system andadvised that possible "adverse airplane vibration effects"may result when the aircraft is operated at speeds in excess of140 mph IAS (about 120 kt). It required that the tab free playbe maintained at less than 0.125 inches and that this should beinspected at 100 hour intervals. FAA AD 73-13-1, dated June 181973, made these requirements Mandatory. Piper Service Letter714 dated June 4 1974 stated that an improved rudder trim mechanismwas available which, if fitted, removed the requirement for the100 hour repetitive inspections and the requirements of the AD.

As part of the AAIB investigation, two independent analyses ofthe rudder and tab hinge moments were carried out. The momentrequired to breakout G-BARB's tab when jammed was measured atabout 35 lb.in, a very low figure. Both analyses showed that if the tab were to jam at around 40° displacement, verylarge rudder hinge moments would occur so that the rudder pedalswould be fully displaced and difficult to move. At the same time,however, aerodynamic forces acting on the tab would generate onlyvery small hinge moments. In different analyses, the tab hingemoments predicted were between 30% and 100% of that required tofree the tab. Flutter analysis showed that the necessary dynamiceffects to cause full rudder deflection could occur at 100 kt,given reasonable assumptions. The likely effects of the fulland instantaneous application of rudder were predicted to includerapid roll, large and oscillatory sideslip angles and lateral'g' forces, and a rapid descent to exceed Vne plus 10% in thedescent (Figure 8) (and Figure 9). The wind drift analysis carried outat the time of the initial investigation showed that the aircraftbroke up at about 1500 ft agl, *ie* 2100 ft amsl.

It was thus concluded that the most probable sequence of eventswas that the tab brackets had sustained cumulative damage overa long period which rapidly progressed during the last flight,until they fractured completely, releasing the tab. Due to anunusual, but not isolated, set of build tolerances the tab jammedcausing the sudden and full application of left rudder. Thisevent created a set of conditions in which the response of theaircraft was rapid and unusual, and highly disorienting to thepilot. During the ensuing descent the pilot attempted to regaincontrol and during the recovery the aircraft broke up due to thehigh speed, the load factor, or both. It is not possible to bespecific about the mechanism which led to the breakup of the tabbrackets but it seems most likely that the tab damage and crackingcaused the tab free play tolerance to be exceeded. As the freeplay in the tab system increased, the damage would have accumulated. At some stage the rudder motions were sufficient to cause finecracks to occur in the paint of the rudder skins, allowing corrosionto start. This must have been some considerable time before theaccident flight. Immediately before the accident flight a pre-flightexternal check was carried out and it seems highly unlikely thatthe tab was already disconnected at that time, however the tabbrackets may have been badly cracked. Such damage can increasein a highly non-linear manner and it appeared probable that betweentakeoff and top of climb the cracking progressed to complete failureof the tab brackets.

FAR 23.629 sub para (f) states "Freedom from flutter, controlreversal and divergence up to Vd/Md must be shown.....after thefailure, malfunction or disconnection of any single element inthe primary flight control system, any tab control system, orany flutter damper." BCAR 23.673 "Primary Flight Controls"differs from FAR 23.673 at para (b) and states "Primary flightcontrol systems must be designed to minimise the likelihood ofcomplete loss of lateral, longitudinal and directional controldue to failure or jamming of any connecting or transmitting elementin the control system." It is clear that the intent of theserequirements is that disconnection of a tab should not createundue control difficulties. Compliance has been achieved in variousways on different aircraft but a key element has been the acceptancethat whilst a disconnected tab may induce marked vibration ofthe associated control surface(s), it should not seriously affectcontrol of the aircraft. In the case of the Beech Travelair,G-ATRC, the control of the aircraft was very seriously affectedand it appears probable that G-BARB may have been similarly affected.

The use of tabs creates the possibility of unusual control behaviourif a tab becomes uncontrolled and remains attached to its controlsurface. This investigation has established that for the existingGA fleet such failures may not be benign, yet the design, constructionand maintenance of associated tab systems are based on the assumptionthat the design achieves the intent of the certification requirements. Since fleetwide modifications of all types is clearly impractical,it is considered that the best approach would be to improve themaintenance of such tab systems. The evidence found in this investigationsuggests that tab systems could be better maintained and documented. Engineers should be made more aware of the potentially criticalconsequences of failure of these components, and the need to achievemanufacturers' recommendations regarding free play and rigging. The following Safety Recommendations are therefore made:

96-44:	The FAA, in conjunction with the Piper Aircraft Company, should assess the potential for rudder trim tabs on Piper PA-34 Seneca aircraft to jam against rudder skins, due to dimensional tolerances between tab rivets and rudder skins, if such tabs suffer control input disconnect. The FAA should also consider including other types, and manufacturers, in such an assessment of the potential jamming mechanisms on uncontrolled trim tabs.
96-45:	The FAA should publish advice to private pilots, engineers and maintenance organisations emphasising the need for correct maintenance of trim tab control systems particularly in respect of free play and stiffness, and the need to correctly document and report defects to airworthiness and design authorities; also to ensure that any associated repairs are carried out in accordance with an approved repair scheme, taking due account of any additional requirements such as the rebalancing of the surfaces, if necessary.